true that the phenomena of lake margins are closely paralleled by those of tide-washed coasts, but this, unfortunately, does not render the literature of the latter the more applicable, for there is a tendency to ascribe to the action of tides features which the students of inland lakes are compelled to account for independently of that agent.

It should be noted also that the point of view of the civil engineer is somewhat different from that of the present study. He is, indeed, concerned with all the forms into which the shore material is wrought by the action of the waves, but he is not at all concerned with their internal structure; and he knows them, moreover, only as subaqueous banks to be determined by sounding, and not at all as features of the dry land. The geologic student has, too, some facilities for study which the engineer lacks, for he is frequently enabled to investigate the anatomy of shore structures by means of natural cross-sections, while the engineer is restricted to an examination of their superficial forms.

Earth Shaping

The earth owes its spheroidal form to attraction and rotation. It owes its great features of continent and ocean bed to the unequal distribution of the heterogeneous material of which it is composed. Many of its minor inequalities can be referred to the same cause, but its details of surface are chiefly moulded by the circulation of the fluids which envelop it. This shaping or moulding of the surface may be divided into three parts—subaërial shaping (land sculpture), subaqueous shaping, and littoral shaping. In each case the process is threefold, comprising erosion, transportation, and deposition.

In subaërial or land shaping the agents of erosion are meteoric—rain, acting both mechanically and chemically, streams, and frost. The agent of transportation is running water. The condition of deposition is diminishing velocity.

In subaqueous shaping, or the moulding of surface which takes place beneath lakes and oceans, currents constitute the agent of erosion. They constitute also the agent of transportation; and the condition of deposition is, as before, diminishing velocity.

In littoral shaping, or the modelling of shore features, waves constitute the agent of erosion. Transportation is performed by waves and currents acting conjointly, and the condition of deposition is increasing depth.

On the land the amount of erosion vastly exceeds the amount of deposition. Under standing water erosion is either *nil* or incomparably inferior in amount to deposition. And these two facts are correlatives, since the product of land erosion is chiefly deposited in lakes and oceans, and the sediments of lakes and oceans are derived chiefly from land erosion. The products of littoral erosion undergo division, going partly to littoral deposition and partly to subaqueous deposition. The material for littoral deposition is derived partly from littoral erosion and partly from land erosion.

That is to say, the detritus worn from the land by meteoric agents is transported outward by streams. Normally it is all carried to the coast, but owing to the almost universal complication of erosion with local uplift, there is a certain share of detritus deposited upon the basins and lower slopes of the land. At the shore a second division takes place, the minor portion being arrested and built into various shore structures, while the major portion continues outward and is deposited in the sea or lake. The product of shore erosion is similarly divided. A part remains upon the shore, where it is combined with material derived from the land, and the remainder goes to swell the volume of subaqueous deposition.

The forms of the land are given chiefly by erosion. Since the wear by streams keeps necessarily in advance of the waste of the intervening surfaces, and since, also, there is inequality of erosion dependent on diversity of texture, land forms are characterised by their variety.

The forms of sea beds and lake beds are given by deposition. The great currents by which subaqueous sediments are distributed sweep over the ridges and other prominences of the surface and leave the intervening depressions comparatively currentless. Deposition, depending on retardation of currents, takes place chiefly in the depressions, so that they are eventually filled and a monotonous uniformity is the result.

The forms of the shore are intermediate in point of variety between those of the land and those of the sea bed; and since they alone claim parentage in waves, they are *sui generis*.

Ocean shores are genetically distinguished from lake shores by the co-operation of tides, which cannot fail to modify the work accomplished by waves and wind currents. The shores which constitute the objective basis of the present discussion were tideless; and the discussion is therefore limited to lake shores. It is perhaps to be regretted that the systematic treatment here proposed could not be extended so as to include all shores, but there is a certain compensation in the fact that the results reached in reference to lake shores have an important negative bearing on tidal discussions. It was long ago pointed out by Élie de Beaumont[1] and Desor[2] that many of the more important features ascribed by hydraulic engineers to tidal action, are produced on the shores of inland seas by waves alone; and the demonstration of wave-work pure and simple should be serviceable to the maritime engineer by pointing out the results in explanation of which it is unnecessary to appeal to the agency of tides.

CAPILLARY ATTRACTION

THE heaviness of matter had been known for as many thousand years as men and philosophers had lived on the earth, but none had suspected or imagined, before Newton's discovery of universal gravitation, that heaviness is due to action at a distance between two portions of matter. Electrical attractions and repulsions, and magnetic attractions and repulsions, had been familiar to naturalists and philosophers for two or three thousand years. Gilbert, by showing that the earth, acting as a great magnet, is the efficient cause of the compass needle's pointing to the north, had enlarged people's ideas regarding the distances at which magnets can exert sensible action. But neither he nor any one else had suggested that heaviness is the resultant of mutual attractions between all parts of the heavy body and all parts of the earth, and it had not entered the imagination of man to conceive that different portions of matter at the earth's surface, or even the more dignified masses called the heavenly bodies, mutually attract one another. Newton did not himself give any observational or experimental proof of the mutual attraction between any two bodies, of which both are smaller than the moon. The smallest case of gravitational action which was included in the observational foundation of his theory, was that of the moon on the waters of the ocean, by which the tides are produced; but his inductive conclusion that the heaviness of a piece of matter at the earth's surface, is the resultant of attractions from all parts of the earth acting in inverse proportion to squares of distances, made it highly probable that pieces of matter within a few feet or a few inches attract one another according to the same law of distance, and Cavendish's splendid experiment verified this conclusion. But now for our question of this evening. Does this attraction between any particle of matter in one body and any particle of matter in another continue to vary inversely as the square of the distance, when the distance between the nearest points of the two bodies is diminished to an inch (Cavendish's experiment does not demonstrate this, but makes it very probable), or to a centimetre, or to the hundred-thousandth of a centimetre, or to the hundred-millionth of a centimetre? Now I dip my finger into this basin of water; you see proved a force of attraction between the finger and the drop hanging from it, and between the matter on the two sides of any horizontal plane you like to imagine through the hanging water. These forces are millions of times greater than what you would calculate from the Newtonian law, on the supposition that water is perfectly homogeneous. Hence either these forces of attraction must, at very small distances, increase enormously more rapidly than according to the Newtonian law, or the substance of water is not homogeneous. We now all know that it is not homogeneous. The Newtonian theory of gravitation is not surer to us now than is the atomic or molecular theory in chemistry and physics; so far, at all events, as its assertion of heterogeneousness in the minute structure of matter apparently homogeneous to our senses and to our most delicate direct instrumental tests. Hence, unless we find heterogeneousness and the Newtonian law of attraction incapable of explaining cohesion and capillary attraction, we are not forced to seek the explanation in a deviation from Newton's law of gravitational force. In a little communication to the Royal Society of Edinburgh twenty-four years ago,[1] I showed that heterogeneousness does suffice to account for any force of cohesion, however great, provided only we give sufficiently great density to the molecules in the heterogeneous structure.

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[1] "Leçons de Géologie pratique," Paris, 1845, v. i. p. 232.

[2] "Geology of Lake Superior Land District," by Foster and Whitney, Washington, 1851, v. ii. pp. 262, 266.

Nothing satisfactory, however, or very interesting mechanically, seems attainable by any attempt to work out this theory without taking into account the molecular motions which we know to be inherent in matter, and to constitute its heat. But so far as the main phenomena of capillary attraction are concerned, it is satisfactory to know that the complete molecular theory could not but lead to the same resultant action in the aggregate as if water and the solids touching it were each utterly homogeneous to infinite minuteness, and were acted on by mutual forces of attraction sufficiently strong between portions of matter which are exceedingly near one another, but utterly insensible between portions of matter at sensible distances. This idea of attraction insensible at sensible distances (whatever molecular view we may learn, or people not now born may learn after us, to account for the innate nature of the action), is indeed the key to the theory of capillary attraction, and it is to Hawksbee[2] that we owe it. Laplace took it up and thoroughly worked it out mathematically in a very admirable manner. One part of the theory which he left defective—the action of a solid upon a liquid, and the mutual action between two liquids—was made dynamically perfect by Gauss, and the finishing touch to the mathematical theory was given by Neumann in stating for liquids the rule corresponding to Gauss's rule for angles of contact between liquids and solids.

Gauss, expressing enthusiastic appreciation of Laplace's work, adopts the same fundamental assumption of attraction sensible only at insensible distances, and, while proposing as chief object to complete the part of the theory not worked out by his predecessor, treats the dynamical problem afresh in a remarkably improved manner, by founding it wholly upon the principle of what we now call potential energy. Thus, though the formulas in which he expresses mathematically his ideas are scarcely less alarming in appearance than those of Laplace, it is very easy to translate them into words by which the whole theory will be made perfectly intelligible to persons who imagine themselves incapable of understanding sextuple integrals. Let us place ourselves conveniently at the centre of the earth so as not to be disturbed by gravity. Take now two portions of water, and let them be shaped over a certain area of each, call it A for the one, and B for the other, so that when put together they will fit perfectly throughout these areas. To save all trouble in manipulating the supposed pieces of water, let them become for a time perfectly rigid, without, however, any change in their mutual attraction. Bring them now together till the two surfaces A and B come to be within the one-hundred-thousandth of an inch apart, that is, the forty-thousandth of a centimetre, or two hundred and fifty micro-millimetres (about half the wave-length of green light). At so great a distance the attraction is quite insensible: we may feel very confident that it differs, by but a small percentage, from the exceedingly small force of attraction which we should calculate for it according to the Newtonian law, on the supposition of perfect uniformity of density in each of the attracting bodies. Well known phenomena of bubbles, and of watery films wetting solids, make it quite certain that the molecular attraction does not become sensible until the distance is much less than 250 micro-millimetres. From the consideration of such phenomena Quincke (*Pogg. Ann.*, 1869) came to the conclusion that the molecular attraction does become sensible at distances of about fifty micro-millimetres. His conclusion is strikingly confirmed by the very important discovery of Reinold and Rücker that the black film, always formed before an undisturbed soap bubble breaks, has a uniform or nearly uniform thickness of about eleven or twelve micro-millimetres. The abrupt commencement, and the permanent stability, of the black film demonstrate a proposition of fundamental importance in the molecular theory:—The tension of the film, which is sensibly constant when the thickness exceeds fifty micro-millimetres, diminishes to a minimum, and begins to increase again when the thickness is diminished to ten micro-millimetres. It seems not possible to explain this fact by any imaginable law of force between the different portions of the film supposed homogeneous, and we are forced to the conclusion that it depends upon molecular heterogeneousness. When the homogeneous molar theory is thus disproved by observation, and its assumption of a law of attraction augmenting more rapidly than according to the Newtonian law when the distance becomes less than fifty micro-millimetres is proved to be insufficient, may we not go farther and say thet it is unnecessary to assume any deviation from the Newtonian law of force varying inversely as the square of the distance continuously from the millionth of a micro-millimetre to the remotest star or remotest piece of matter in the universe; and, until we see how gravity itself is to be explained, as Newton and Faraday thought it must be explained, by some continuous action of intervening or surrounding matter, may we not be temporarily satisfied to explain capillary attraction merely as Newtonian attraction intensified in virtue of intensely dense molecules movable among one another, of which the aggregate constitutes a mass of liquid or solid.

But now for the present, and for the rest of this evening, let us dismiss all idea of molecular theory, and think of the molar theory pure and simple, of Laplace and Gauss. Returning to our two pieces of rigidified water left at a distance of 250 micro-millimetres from one another. Holding them in my two hands, I let them come nearer and nearer until they touch all along the surfaces A and B. They begin to attract one another with a force which may be scarcely sensible to my hands when their distance apart is fifty micro-millimetres, or even as little as ten micro-millimetres; but which certainly becomes sensible when the distance becomes one micro-millimetre, or the fraction of a micro-millimetre; and enormous, hundreds or thousands of kilogrammes' weight, before they come into absolute contact. I am supposing the area of each of the opposed surfaces to be a few square centimetres. To fix the ideas, I shall suppose it to be exactly thirty square centimetres. If my sense of force were sufficiently metrical I should find that the work done by the attraction of the rigidified pieces of water in pulling my two hands together was just about four and a half centimetre-grammes. The force to do this work, if it had been uniform throughout the space of fifty micro-millimetres (five-millionths of a centimetre) must have been nine hundred thousand grammes weight, that is to say, nine-tenths of a ton. But in reality it is done by a force increasing from something very small at the distance of fifty micro-millimetres to some unknown greatest amount. It may reach a maximum before absolute contact, and then begin to diminish, or it may increase and increase up to contact, we cannot tell which. Whatever may be the law of variation of the force, it is certain that throughout a small part of the distance it is considerably more than one ton. It is possible that it is enormously more than one ton, to make up the ascertained amount of work of four and a half centimetre-grammes performed in a space of fifty micro-millimetres.

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[1] *Proceedings* of the Royal Society of Edinburgh, April 21, 1862 (vol. iv.).
[2] Royal Society *Transactions*, 1709-13.

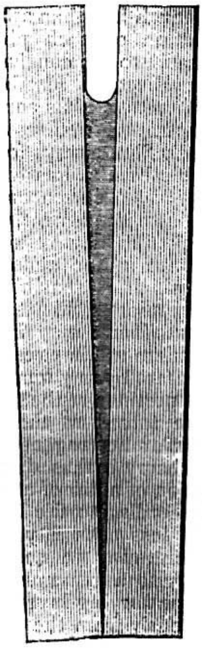

FIG. 1.

But now let us vary the circumstances a little. I take the two pieces of rigidified water, and bring them to touch at a pair of corresponding points in the borders of the two surfaces A and B, keeping the rest of these surfaces wide asunder (see Fig. 1). The work done on my hands in this proceeding is infinitesimal. Now, without at all altering the law of attractive force, let a minute film of the rigidified water become fluid all over each of the surfaces A and B: you see exactly what takes place. The pieces of matter I hold in my hands are not the supposed pieces of rigidified water. They are glass, with the surfaces A and B thoroughly clean and wetted all over each with a thin film of water. What you now see taking place is the same as what would take place if things were exactly according to our ideal supposition. Imagine, therefore, that there are really two pieces of water, all rigid, except the thin film on each of the surfaces A and B, which are to be put together. Remember also that the Royal Institution, in which we are met, has been, for the occasion, transported to the centre of the earth so that we are not troubled in any way by gravity. You see we are not troubled by any trickling down of these liquid films—but I must not say *down*, we have no up and down here. You see the liquid film does not trickle along these surfaces towards the table, at least you must imagine that it does not do so. I now turn one or both of these pieces of matter till they are so nearly in contact all over the surfaces A and B, that the whole interstice becomes filled with water. My metrical sense of touch tells me that exactly four and a half centimetre-grammes of work has again been done; this time, however, not by a very great force, through a space of less than fifty micro-millimetres, but by a very gentle force acting throughout the large space of the turning or folding-together motion which you have seen, and now see again. We know, in fact, by the elementary principle of work done in a conservative system, that the work done in the first case of letting the two bodies come together directly, and in the second case of letting them come together by first bringing two points into contact and then folding them together, must be the same, and my metrical sense of touch has merely told me in this particular sense what we all know theoretically must be true in every case of proceeding by different ways to the same end from the same beginning.

WILLIAM THOMSON

(*To be continued.*)

THE TOTAL SOLAR ECLIPSE, 1886 *AUGUST* 28-29

THE Eclipse Expedition will leave England on the 29th inst. in the Royal Mail Steamship *Nile*, timed to arrive at Barbados on August 11. We regret to learn that Her Majesty's ship *Canada*, which was told off to assist the Expedition, chiefly by supplying artificers and assistance in camping and in the observations, has been withdrawn on some "diplomatic" service. This is a serious blow to the probabilities of good results.

From data supplied by Mr. Hind, the following details have been computed for the Island of Grenada:—

	Latitude N.	Longitude W.	Commencement of totality G.M.T.	Commencement of totality Local time
	° ′	° ′	h. m. s.	h. m. s.
Levera	12 13·5	61 37	23 17 19	19 10 51
Caliveny	12 0·0	61 43	23 17 14	19 10 22
Point Saline ...	12 0·5	61 48	23 17 10	19 9 58
Fort Frederick.	12 3·0	61 44	23 17 13	19 10 17

	Duration of totality	Sun's Azimuth	Sun's True altitude	Angle from N. point
	m. s.	° ′	° ′	
Levera	3 45	84 12	18 56	87° to W.
Caliveny	3 52	84 6	18 48	73° ,,
Point Saline ...	3 48	84 4	18 42	72° ,,
Fort Frederick.	3 49	84 3	18 46	77° ,,

The sun's altitude and azimuth and the angle from N. point are given for the commencement of totality.

The time of first contact for the middle of the island [assumed lat. 12° 6′·0, long. 61° 43′·0] is 18h. 11m. 55s. local mean time at 77°·0 N. to W. on the sun's limb; and ends at 20h. 20m. 44s. at 105° N. to E. on the limb.

A diagram is given below showing the position of the principal stars and planets at the commencement of totality. The distances of the planets from the sun are very roughly as follows (the positions of Mercury and Venus being shown absolutely, and the directions of the others indicated by arrows):—

Mercury (Me) = 4 | Mars (Ma) = 15
Venus (V) = 6 | Saturn (S) = 12

$\left.\begin{matrix}\text{Jupiter}\\ \text{Uranus}\end{matrix}\right\}$ almost in conjunction $\left\{\begin{matrix}\text{(J)}\\ \text{(U)}\end{matrix}\right. = 8.$

Local mean time of transit of Polaris and δ Ursæ Minoris for Caliveny (Grenada), long. 61° 43′ W.:—